

What is Claimed is:

1. A sealless blood pump, comprising:

a pump housing, having an inlet tube on one end and an impeller casing on the other end, said casing including a outlet;

5 a rotor mounted for rotation within said housing, said rotor having an elongated shaft portion and an impeller attached to said shaft portion, said impeller being located within said impeller casing;

radial magnetic bearings carried by said shaft portion, and radial magnetic bearings carried by said housing for maintaining said shaft portion of said rotor within said inlet tube of said housing;

10 a rotor motor, said motor including a plurality of permanent magnets carried by said impeller and a motor stator including an electrically conductive coil located within said housing; and

15 a ring of back iron fixed to said casing to aid in completing a flux return path for said permanent magnets.

2. A sealless blood pump as defined in claim 1, in which said conductive coil and said back iron are fixed to said casing and said housing rearwardly of said impeller.

20 3. A sealless blood pump as defined in claim 1, in which said impeller has a forward side facing said inlet tube and a rear side downstream of said forward side, said conductive coil being located adjacent said rear side and said back iron ring being located outside of said conductive coil, within said housing, and fixed
25 to said housing.

4. A sealless blood pump as defined in claim 3, including a second ring of back iron located on the forward side of said impeller and outside of said casing but inside of said housing, said second ring of back iron being fixed to said casing.

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5. A sealless blood pump as defined in claim 4, including a second motor stator having an electrically conductive coil located on the forward side of said impeller outside of said casing but inside of said housing.

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6. A sealless blood pump as defined in claim 5, in which said second ring of back iron is located forward of said second motor stator.

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7. A sealless blood pump, comprising:

a pump housing, having an inlet tube on one end and an impeller casing on the other end, said casing including an outlet;

a rotor mounted for rotation within said housing, said rotor having an elongated shaft portion and an impeller attached to said shaft portion, said impeller being located within said impeller casing;

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radial magnetic bearings carried by said shaft portion, and radial magnetic bearings carried by said housing for maintaining said shaft portion of said rotor within said inlet tube of said housing;

a rotor motor, said motor including a plurality of permanent magnets carried by said impeller and a motor stator including an electrically conductive coil located within said housing; and

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a ring of back iron carried by said impeller to aid in completing a flux return path for said permanent magnets, said ring of back iron being located at the

forward side of said impeller and within said casing.

8. A sealless blood pump as defined in claim 7, in which said rotor motor is a radial flux gap motor and said plurality of permanent magnets located
5 within said impeller extend in radial alignment with said motor stator.

9. A sealless blood pump as defined in claim 7, in which said ring of back iron is generally aligned with said permanent magnets and is located radially inside said permanent magnets.

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10. A sealless blood pump as defined in claim 7, including permanent magnetic bearings located at the rear side of said impeller.

11. A sealless blood pump as defined in claim 10, in which said
15 permanent magnetic bearings comprise first permanent magnets carried by said impeller at the rear end thereof and second permanent magnets downstream of said first permanent magnets and fixed to said casing and housing.

12. A sealless blood pump, comprising:
20 a pump housing, having an inlet tube on one end and an impeller casing on the other end, said casing including an outlet;

a rotor mounted for rotation within said housing, said rotor having an elongated shaft portion and an impeller attached to said shaft portion, said impeller being located within said impeller casing;

25 radial magnetic bearings carried by said shaft portion, and radial magnetic bearings carried by said housing for maintaining said shaft portion of said rotor

within said inlet tube of said housing;

a rotor motor, said motor including a plurality of permanent magnets carried by said impeller and a motor stator including an electrically conductive coil located within said housing; and

5 a plurality of hydrodynamic thrust bearings located outside of the axis of rotation of said rotor.

10 13. A sealless blood pump as defined in claim 12, in which said hydrodynamic bearings are wedge-shaped.

14. A sealless blood pump as defined in claim 12, in which during rotation of said rotor and impeller, said hydrodynamic bearings are separated from said casing by a fluid film and are not in direct mechanical contact with said casing.

15 15. A sealless blood pump as defined in claim 12, in which said hydrodynamic bearings are arcuate and are located on the forward side of said impeller.

20 16. A sealless blood pump as defined in claim 12, in which at least some of said hydrodynamic thrust bearings are carried by said impeller.

17. A sealless blood pump as defined in claim 12, in which at least some of said hydrodynamic thrust bearings are carried by said casing.

25 18. A sealless blood pump as defined in claim 12, including a casing reinforcement member on the rear side of said casing, carrying said

hydrodynamic bearings.

19. A sealless blood pump, comprising:

5 a pump housing, having an inlet tube on one end and an impeller casing on the other end, said casing including an outlet;

a rotor mounted for rotation within said housing, said rotor having an elongated shaft portion and an impeller attached to said shaft portion, said impeller being located within said impeller casing;

10 said impeller comprising a disk-shaped member having a central, upper face portion attached to one end of said shaft, said impeller having a plurality of blade sectors, each of said sectors being separated from an adjacent sector by a channel extending from said upper face portion to a lower face portion;

said channels serving as a fluid path through the impeller and functioning to increase the effective working area of the impeller; and

15 a plurality of hydrodynamic thrust bearings located outside of the axis of rotation of said rotor.

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20. A sealless blood pump as defined in claim 19, including radial magnetic bearings carried by said shaft portion, and radial magnetic bearings carried by said housing for maintaining said shaft portion of said rotor within said inlet tube of said housing.

21. A sealless blood pump as defined in claim 19, including a rotor motor, said motor including a plurality of permanent magnets carried by said impeller
25 and a motor stator including an electrically conductive coil located within said housing.

22. A sealless blood pump as defined in claim 21, including a ring of back iron fixed to said casing to aid in completing a flux return path for said permanent magnets.

5 23. A sealless blood pump as defined in claim 22, including a second ring of back iron located on the forward side of said impeller and outside of said casing but inside of said housing, said second ring of back iron being fixed to said casing.

10 24. A sealless blood pump as defined in claim 21, including a second motor stator having an electrically conductive coil located on the forward side of said impeller outside of said casing but inside of said housing.

15 25. A sealless blood pump, comprising:
a pump housing, said housing having an inlet tube on one end and an impeller casing on the other end, said casing including a discharge tube;

20 a rotor mounted for rotation within said housing, said rotor having an elongated shaft portion and an impeller attached to said shaft portion, said impeller being located within said impeller casing and having a diameter between 1 inch and 1.5 inch;

radial magnetic bearings carried by said shaft portion, and radial magnetic bearings carried by said housing for maintaining said shaft portion of said rotor coaxially within said inlet tube of said housing, a primary flow channel for blood being provided by an annular volume between said shaft and said radial magnetic bearings carried by said housing, said primary flow channel having a thickness
25 between .06 inch and .1 inch.

26. A sealless blood pump as defined in claim 25, in which the axial length of the entire pump is 1.75 inch to 3.0 inch.

27. A sealless blood pump as defined in claim 25, in which the rotor diameter is .025 inch to 0.4 inch and the axial length of the impeller is 0.2 inch to 0.5 inch.

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28. A sealless blood pump, comprising:

a pump housing, having an inlet tube on one end and an impeller casing on the other end, said casing including an outlet;

a rotor mounted for rotation within said housing, said rotor having an elongated shaft portion and an impeller attached to said shaft portion, said impeller being located within said impeller casing;

a rotor motor, said motor including a plurality of permanent magnets carried by said impeller, a first motor stator including an electrically conductive coil located within said housing and a second motor stator including an electrically conductive coil located within said housing;

said first motor stator and said second motor stator being located on opposite sides of said impeller.

29. A sealless blood pump as defined in claim 28, including a ring of back iron fixed to said casing to aid in completing a flux return path for said permanent magnets.

30. A sealless blood pump as defined in claim 29, including a

second ring of back iron located on the opposite side of said impeller from said first mentioned ring of back iron, said second ring of back iron being fixed to said casing.

31. A sealless blood pump as defined in claim 30, in which said
5 rings of back iron are located outside of said casing but inside of said housing.

32. A sealless blood pump as defined in claim 28, including a
plurality of hydrodynamic thrust bearings located outside of the axis of rotation of said
rotor.

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33. A sealless blood pump, comprising:

an impeller comprising a disk-shaped member having a diameter between
1 inch and 1.5 inch;

an impeller shaft;

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said impeller including a central, upper face portion attached to one end
of said shaft;

said impeller having a plurality of blade sectors, each of said sectors
being separated from an adjacent sector by a channel extending from said upper face
portion to a lower face portion;

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said impeller blade depth being between 0.2 inch and 0.5 inch;

said channels having a width between .05 inch to 0.2 inch;

said channels serving as a fluid path through the impeller and functioning
to increase the effective working area of the impeller.

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34. A sealless blood pump as defined in Claim 33, in which said
impeller carries plurality of permanent magnets.

35. A sealless blood pump as defined in Claim 33, including a pump housing, having an inlet tube on one end and an impeller casing on the other end, said casing including an outlet; a rotor mounted for rotation within said housing, said rotor comprising said impeller shaft, said impeller being located within said
5 impeller casing.

36. A sealless blood pump, comprising:
a pump housing, having an inlet tube on one end and an impeller casing on the other end, said casing including an outlet;
10 a rotor mounted for rotation within said housing, said rotor having an elongated shaft portion and an impeller attached to said shaft portion, said impeller being located within said impeller casing;
a rotor motor, said motor including a plurality of magnets carried by said impeller and a motor stator including an electrically conductive coil and a pole piece
15 located within said housing, said magnets and said stator being positioned to function to transmit torque and to provide a restoring radial magnetic force between said stator and magnets that would tend to return a radially deflected impeller to a neutral position.

20 37. A sealless blood pump as defined in Claim 36, in which said pole piece comprises teeth extending from a ring of back iron.

38. A sealless blood pump as defined in Claim 36, including a
25 plurality of hydrodynamic thrust bearings located outside of the axis of rotation of said rotor.

39 A sealless blood pump as defined in Claim 36, in which said
impeller comprises a disc-shaped member having a central, upper face portion attached
to one end of said shaft, said impeller having a plurality of blade sectors, each of said
sectors being separated from an adjacent sector by a channel extending from said upper
5 face portion to a lower face portion, said magnets being positioned within said blade
sectors in radial alignment with said pole piece.